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Technical Report

Environmental Life Cycle Implications of Fuel Oxygenate Production from California Biomass - Executive Summary

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EXECUTIVE SUMMARY

PROJECT OVERVIEW

The open burning of biomass generates significant air emissions annually in California. Historically, some important sources of these emissions have been the open-field burning of excess rice straw, and the burning of forest residue and chaparral. These can especially be of concern where they are emitted during days when ground-level ozone concentrations are elevated. Open burning can be seen as a "disposal method" for these biomass sources. One means of reducing air emissions and other negative impacts associated with this disposal method is to use this biomass as a feedstock for ethanol production. Biomass-derived ethanol can be used as a fuel oxygenate, either by itself or in the form of its ether derivative, ethyl tertiary-butyl ether (ETBE). This oxygenate can be used as a substitute for methyl tertiary-butyl ether (MTBE), which is currently being used in reformulated gasoline in the state of California and elsewhere in the United States. Therefore, the focus of this report is to quantify and compare the comprehensive environmental flows over the life cycles of two disposal scenarios: (1) the burning of the biomass plus the production and use of MTBE, and (2) the conversion of the biomass into ETBE and its subsequent use.

To facilitate the presentation of results, these two scenarios are referred to as the MTBE scenario and the ETBE scenario, respectively. The results of the study were compared in terms of potential impacts of the pollutants emitted (e.g., greenhouse gases, acidification potential, etc.). This was not a risk assessment study and did not consider MTBE or ETBE contamination of groundwater. A study of this nature would need to be site-specific and is outside the scope of this investigation. This report shows the life cycle emissions of the two scenarios, meaning that the results are summarized over different locations and different time frames. Therefore, it does not take into account the fact that open burning results in a pulse of emissions at one time and location versus ETBE combustion in a vehicle that takes place over a longer period of time and at different locations. This report only shows the difference in the total emissions of the two options and does not account for concentrations of pollutants at a given time. For the same reasons, ozone-forming potential was not calculated, which again would require site- and time-dependent data that were not collected for this study.

BIOETHANOL AND ETBE PRODUCTION POTENTIAL

Table 1 summarizes the volumes of ethanol and ETBE that could be produced if all of the biomass that is available and can be collected in California is converted to ethanol. While not all of the accessible biomass would likely be available for ethanol and ETBE production, these values are illustrative. More discussion of the availability of the biomass types can be found in Appendix C.

Table 1: Biomass-Derived Ethanol and ETBE Production Potential in California

Biomass Source	***Estimated Availability in California*** million metric bone dry tons/yr	***Ethanol Production Method***	***Ethanol Production Potential*** million liters/yr	***ETBE Production Potential*** million liters/yr
Rice Straw	1.4	Enzyme	439.7	1,033.7
		Acid	396.4	932.0
Forest Residue	5.7	Enzyme	1,965.0	4,619.0
		Acid	1,596.7	3,753.0
Chaparral	2.0	Enzyme	235.7	553.9
		Acid	211.3	496.7

Of the amount of MTBE that is consumed annually in California, only 15% is produced within the state; the remaining 85% is imported. Therefore, using existing plant capacity for ether production and infrastructure, only the 15% in-state production can potentially be offset in the near-term. Table 2 gives an idea of how much ETBE could be produced in California each year using this approach. There are some options available for satisfying the rest of the oxygenate demand using biomass-derived ETBE; however, their feasibility would depend on economical and market factors, which are beyond the scope of this study. It should be noted that this limitation only applies to ethers, and that biomass-derived ethanol produced within the state can potentially fulfill the entire oxygenate demand. This option was analyzed as part of the sensitivity analysis discussed later.

Table 2: Near-Term ETBE Production in California

MTBE Produced in California		***ETBE Needed on Oxygen-Equivalent Basis***	***ETBE Needed for Near-Term Scenario***	
million liters/yr	thousand metric tons/yr	kg ETBE/kg MTBE	million liters/yr	thousand metric tons/yr
56.8	42.2	1.162	65.8	49.0

Table 3 summarizes the amounts of ethanol and ETBE that can be produced by biomass type and by ethanol production method. These values are normalized for one metric bone-dry ton of biomass. The final two columns also show the equivalent amount of MTBE and gasoline this amount of ETBE would displace. That is, the 549.7 kg of ETBE produced from rice straw using the enzyme process would offset the use of 472.7 kg of MTBE and 77 kg of gasoline. This difference is because ETBE has a slightly higher heating value than MTBE.

Table 3: Ethanol and ETBE Yield by Biomass Type

Biomass Source One metric bone dry ton (1000 kg)	***Ethanol Production Method***	***Ethanol Produced*** (liters)	***ETBE Produced***[a] (liters)	***Equivalent in MTBE plus Gasoline*** MTBE (liters)	Gasoline (liters)
Rice Straw	Enzyme	314.1	738.3	635.9	104.3
	Acid	283.2	665.7	573.4	94.0
Forest Residue	Enzyme	344.7	810.3	698.1	114.2
	Acid	280.1	658.4	567.2	92.9
Chaparral	Enzyme	117.8	277.0	238.6	39.0
	Acid	105.7	248.4	213.9	35.1

[a]Ethanol and isobutylene are reacted to produce ETBE; hence, the increase in volume.

BASELINE RESULTS

The results of the study are presented for six scenarios modeled using different feedstocks and methods of producing ethanol. More precisely, each of the three feedstocks (rice straw, forest residue, and chaparral) was modeled using an enzyme process and a concentrated acid process to produce ethanol. These scenarios follow the base-case assumption that the entire amount of lignin-rich residue generated during the production of ethanol is used for on-site cogeneration of steam and electricity.

In terms of net environmental flows, the production of ETBE from any of the three biomass feedstocks produces lower emissions than open-field burning the biomass and the production of MTBE. Specifically, criteria air pollutants—including non-methane hydrocarbons, carbon monoxide, oxides of nitrogen and particulates—show significantly lower net emissions with the production of ETBE. However, in the production of ethanol for ETBE, higher water effluents (e.g., nitrates) result.

Table 4 summarizes the differences between the two scenarios for criteria air pollutants, carbon dioxide, and energy consumption. The differences are expressed as percentages by which the values for the ETBE scenario were different from those for the MTBE scenario [i.e., 100x(MTBE value–ETBE value)/MTBE value]. A positive value indicates the percentage by which the values for the ETBE scenario were lower than those for the MTBE scenario and vice versa. For example, the ETBE scenario, with rice straw conversion via enzymatic hydrolysis, had a 97% reduction in carbon monoxide emissions compared to those for the MTBE scenario.

Table 4: Relative Differences between ETBE Scenario and MTBE Scenario

Environmental Flow	***Rice Straw***		***Forest Residue***		***Chaparral***	
	Enzyme	***Acid***	***Enzyme***	***Acid***	***Enzyme***	***Acid***
Carbon Monoxide	97%	95%	98%	98%	97%	96%
Non-methane Hydrocarbons	61%	64%	57%	61%	97%	89%
Nitrogen Oxides (NO_x)	69%	57%	69%	54%	23%	**-102%**
Particulates	89%	44%	93%	68%	96%	81%
Sulfur Oxides (SO_x)	84%	81%	87%	79%	83%	58%
Carbon Dioxide	52%	25%	58%	35%	68%	-9%
Total Energy Consumption	16%	**-26%**	23%	**-15%**	6%	**-115%**

It should be noted that this report shows the life cycle emissions of the two options, meaning that the results are summarized over different locations and different time frames. Therefore, it does not take into account the fact that open burning results in a pulse of emissions at one time and location versus ETBE combustion in a vehicle that takes place over a period of time and at different locations. This report only shows the difference in the total emissions of the two options and does not account for concentrations of pollutants at a given time.

Rice Straw

For the rice straw feedstock using the enzyme process scenario, the conversion of the biomass to ETBE leads to a decrease from the MTBE scenario for almost all of the environmental flows. The one exception is nitrates in water run-offs.

Nitrates (which are not listed in Table 4 above) are significantly higher for the ETBE scenario mainly because of the use of corn steep liquor (CSL) during ethanol fermentation. Agricultural operations lead to water run-offs containing fertilizer-derived nitrates. CSL is a by-product of corn wet-milling and has nitrates emissions associated with its production. It is, however, not mandatory that CSL be used during ethanol fermentation, and non-agricultural based alternatives are possible. It should be noted that the nitrates emissions occur at the geographical site where corn is grown, i.e., near the farm.

The four impact assessment categories—eutrophication potential, depletion of natural resources, greenhouse gas potential, and air acidification potential—show lower values for the ETBE scenario than for the MTBE scenario. Thus, despite higher nitrates values, the ETBE scenario shows a lower eutrophication potential. Also, the renewable portion of the total energy consumed is higher for the ETBE scenario than for the MTBE scenario. Using a renewable resource such as biomass in general helps to reduce the depletion of nonrenewable resources, and power generation using a low-sulfur residue allows for lower SO_x emissions and air acidification.

The relative life cycle flows are mostly similar when a concentrated acid process is used instead of an enzymatic process for ethanol production. In terms of the criteria pollutants, the acid-based process results in higher emissions than the enzyme-based process; however, the emissions are still lower than the emissions for the MTBE scenario. The major difference arises from the fact that the acid process requires more energy than the enzyme process in the form of natural gas used to generate steam, contributing to the criteria pollutants. Also, use of additional natural gas in the concentrated acid process leads to a greater depletion of natural resources than that for the MTBE scenario.

Forest Residue

The forest residue yields results similar to those for rice straw. Rice straw is burned in place, whereas forest residue is collected before burning. In spite of this, the reduction in total energy consumption (compared to the MTBE scenario) is higher for forest residue. This is attributable to the lower heating value of the rice-straw fuel residue due to its high silica content.

Chaparral

For chaparral conversion via the enzymatic process, the ETBE scenario yields values that are much lower than those for the MTBE scenario for most of the environmental flows. The exceptions are those values that are dependent on ethanol production, such as nitrates. Many of the other emissions for the ETBE scenario are lower because of the relatively high amount of lignin in chaparral. This leads to lower SO_x, NO_x, and fossil CO_2 emissions because of the correspondingly high electricity offset credits. Additionally, chaparral is also high in extractives, which are converted to biogas during wastewater treatment. The biogas is used as an energy source, which also provides similar offset credits. For these reasons, chaparral yields lower values—when compared to either forest residue or rice straw—for the four impact categories examined—eutrophication, depletion of natural resources, air acidification, and greenhouse gas potential. Chaparral also results in lower emissions of the criteria pollutants than those for forest residue or rice straw.

Another key observation is that the reduction in total energy consumption (compared to the MTBE scenario) is the lowest for chaparral. This is because of higher energy required during its collection and during ethanol distillation, which receives a more dilute feed due to chaparral's low sugar content.

Using the concentrated acid process instead of the enzyme process yields similar relative performance of the ETBE option versus the MTBE option. The general discussion above regarding the differences between the two ethanol processes using rice straw applies also to chaparral.

SENSITIVITY ANALYSIS

The results presented above were relative to the base case for the ETBE scenario, i.e., on-site cogeneration of steam and electricity using the ligneous residue generated during the production of ethanol, and etherification of ethanol to yield ETBE. To gain further insights into the process, two variations on the theme were evaluated: 1) Shipping the fuel residue off-site to an existing biomass power plant, and 2) bypassing etherification and using ethanol itself as an oxygenate. These are elucidated below.

Shipping of Fuel Residue

Shipping the fuel residue off-site to an existing biomass power plant is another practical way to utilize fuel residue without having to build an on-site power plant. The emissions related to drying the residue further and transporting it a given distance (50 miles was the distance used in the analysis) are added to the ETBE scenario. The differences between the two scenarios are lower than those for the base case; however, the general conclusions do not change.

10% Ethanol Blend (E10)

The environmental impact was evaluated for the case of using ethanol as a direct fuel additive as opposed to transforming the ethanol first into ETBE before being added to gasoline. A blend of 10% by volume of ethanol with gasoline was used to model an ethanol-based reformulated gasoline. The 10% blend (referred to as E10) was used as it represents a fairly standard blend of ethanol with gasoline and has similar properties as MTBE reformulated gasoline.

As opposed to the baseline model, there is a difference in the emissions from the combustion of E10 reformulated gasoline versus MTBE reformulated gasoline. This is because in the baseline model both the fuels have the same oxygen level and heating value. In this case study, the two fuels have the same heating value but not the same oxygen level; the E10 blended fuel has 3.5% oxygen compared to 2% oxygen for the baseline fuel. The difference in the composition of the fuels causes differences in the tailpipe emissions of vehicles using the fuels. Therefore, the emissions from the combustion of the fuels were taken into account in the comparison. Also, the E10 blended fuel has higher evaporative emissions than MTBE blended fuel, so evaporative emissions during blending operations were also taken into account.

Overall, except for water effluents (nitrates and COD) and NO_x emissions, the E10 scenario has lower emission values than those for the MTBE scenario; many of the higher emissions for the E10 option are attributable to the ethanol production step. The differences between this sensitivity scenario and the baseline scenario are due to the fact that more ethanol is required for the former.

A major difference between the E10 and ETBE scenarios is that the E10 scenario is not limited by isobutylene availability, and ethanol produced within the state can potentially satisfy all of the oxygenate demand, i.e., it can substitute MTBE that is produced in the state as well as that is imported.

CONCLUSIONS

It is likely that agricultural burning and forestry residue disposal will be problematic issues in California for the foreseeable future. This study provides specific quantitative data on biomass disposal options in California and environmental implications of ether-based oxygenates for gasoline. While the study does not include information on the current concern over MTBE groundwater contamination, it does provide data on true environmental costs of fuel systems that may be useful for public policy makers now confronting the difficult choices of oxygenate use.

The life cycle assessment performed in this study demonstrates the potentially significant benefits of using ETBE derived from California biomass. Overall, the results show that there is a significant difference between Options 1 and 2 (MTBE scenario and ETBE scenario, respectively); the magnitude of this difference varies with the types of biomass feedstocks and ethanol production processes. However, in all cases, the comparison of the ETBE scenario with the MTBE scenario revealed a fundamental difference in terms of energy derived from renewable sources and concomitant benefits of reduced greenhouse gas emissions. This difference can be significant when aiming to shift fuel choices to renewables.

Important benefits are also found with the ETBE scenario with regard to emissions reductions. The ETBE scenarios have lower net energy consumption and carbon dioxide emissions, which—although not regulated or mandated by state or federal laws—are desirable attributes. Specifically, the following prevailing trends were discernible for the ETBE scenarios

Lower net values for:

- Carbon monoxide
- SO_x and NO_x
- Particulates
- Carbon dioxide
- Fossil energy consumption

Hence, implementation of the ETBE scenario would facilitate the improvement of air quality. Emissions of nitrates in water runoffs, however, were somewhat higher for ETBE production. This is due to the use of CSL during ethanol fermentation. It should be noted that these nitrate emissions are upstream of the ethanol production step and occur at the geographical site where corn is grown.

The four impact assessment categories—eutrophication potential, depletion of natural resources, greenhouse gas potential, and air acidification potential—exhibit lower values for the ETBE scenario as compared to the MTBE scenario. The ETBE scenario manages to achieve a lower eutrophication potential in spite of the higher nitrates values. Hence, the ETBE scenario is shown to commonly exhibit lower values than the MTBE scenario for key environmental criteria, both regulated and unregulated. The same can be said when the E10 scenario is compared with the MTBE scenario if we exclude the case of chaparral-acid process.

Finally, this effort is part of a larger picture for transportation fuels. This work may be used as a stepping stone for future studies to develop additional life cycle inventories, such as those for low-ethanol blends (e.g., 10% ethanol blend using a low RVP gasoline), high-ethanol blends (e.g., E85—85% ethanol, 15% gasoline blend), and others.